Habitat Complexity, Salmonid Use, and Predation of Salmonids at the Bioengineered Revetment at the Maplewood Golf Course on the Cedar River, Washington

Report to the

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by

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ABSTRACT

This study was conducted to determine the influence of modifying a riprap revetment in the Cedar River on seasonal habitat complexity and fish densities. A secondary purpose was to compare predation on salmonids occurring at the new bioengineered revetment with predation at a control area. The revetment under study was modified from a riprap revetment to a bioengineered revetment consisting of rock deflectors, large woody debris (LWD), and upslope vegetation. We compared bi-monthly fish densities and salmonid predation rates by piscivorous fish at the bioengineered revetment, to a control area upstream. The control was a natural bank and was considered representative of other un-reveted banks in the Cedar River. We also compared single observations of winter and spring fish densities at the bioengineered revetment during 1999 and 2000, to those observed at the riprap revetment during spring 1997, and winter 1998, prior to its modification.

Habitat complexity increased at the bioengineered revetment compared to the riprap revetment. The bioengineered revetment created a series of diverse secondary habitat units (backwaters and dead-water pools) that were absent in the riprap revetment. Habitat at the bioengineered revetment consisted of more instream cover and lower water velocities than was present at the original riprap revetment.

Relative densities of salmonid parr and cottids were consistently greater at the bioengineered revetment than at the control during almost all surveys. Juvenile chinook salmon and total salmonid relative densities were generally less at the bioengineered revetment than the control during January through March, but were generally greater at the bioengineered revetment during April through June. The seasonal shift may be due to habitat selection preferences or predator avoidance.

Relative densities of chinook salmon, salmonid parr, total salmonids and cottids were greater at the bioengineered revetment than those at the riprap revetment in 1998 in seven of eight comparisons. Juvenile chinook relative densities were greater in 1999 and 2000 than in 1998 even though they were less than those observed at the control. There were too few fish observed during the spring survey in 1997, 1999, or 2000 to provide a comparison.

Predation on salmonids was relatively low at both sites compared to other reported rates in the Cedar River. A total of 50 fish, 38 salmonid fry and 12 unidentified cottids, were observed in the 366 predator stomach samples. The highest frequency (27%) of a predator species (rainbow trout/steelhead) preying on fish was observed at the bioengineered revetment; all the prey were salmonid fry.

The bioengineered revetment was an improvement compared to the riprap revetment. Habitat complexity was increased, and resulted in greater fish densities relative to the un-reveted control area and the old riprap revetment. Further benefits may have been observed if the rock toe was eliminated or modified to a more gradual slope to the water surface. This, in our opinion, would have provided even better habitat for juvenile salmonids and replaced habitat for potential predators such as cottids. However, removal of the rock toe would have to be examined by engineers and was not addressed as part of our study.

TABLE OF CONTENTS

	Page
LIST OF FIGURES	v
LIST OF TABLES	vi
INTRODUCTION	1
Study Area	1
METHODS	3
Data Analysis	3
Habitat	5
Fish Densities	6
Predation	7
RESULTS	8
Habitat	8
Fish Densities	11
Bi-weekly surveys	11
Pre-and Post-Modification Comparisons	16
Predation	17
DISCUSSION	26
CONCLUSIONS AND RECOMMENDATIONS	28
ACKNOWLEDGMENTS	30
REFERENCES	31
APPENDIX A	34
APPENDIX B	38

LIST OF FIGURES

		Page
Figure 1.	Location of bioengineered revetment and control sites at rkm 6.9 on the Cedar River, Washington.	2
Figure 2.	Top: Original Maplewood riprap revetment, summer 1997. Bottom: Bioengineered revetment with rock deflectors, LWD, and vegetated slopes, winter 1998	4
Figure 3.	Relative densities of juvenile chinook salmon, salmonid parr, total salmonids, and cottids at the bioengineered revetment during 1999	14
Figure 4.	Relative densities of juvenile chinook salmon, salmonid parr, total salmonids, and cottids at the bioengineered revetment during 2000	15
Figure 5.	Comparison of juvenile chinook salmon, salmonid parr, total salmonids, and cottid relative densities during winter (night) 1998 survey (old riprap revetment), and the winters of 1999 and 2000 (bioengineered revetment)	16
Figure 6.	Composition (percent by weight) of ingested food for four species of cottids and three species of salmonids, all >49 mm TL, collected from the bioengineered revetment and control site at rkm 6.9 of the Cedar River, WA, 2000	23
Figure 7.	Composition (percent by weight) of ingested food by date for two species of cottids (>49 mm FL) collected from the bioengineered revetment and control site at rkm 6.9 of the Cedar River, WA, 2000.	24
Figure 8.	Composition (percent by weight) of ingested food by date for rainbow trout >49 mm FL collected from the bioengineered revetment and control site at rkm 6.9 of the Cedar River, WA, 2000	25

LIST OF TABLES

Page

Table 1. Substrate classification used for this study (Cummings 1962) 6

Table 2. Habitat data from the riprap revetment and control in 1997 and 1998; and the bioengineered revetment and control site in 1999 and 2000. 9

Table 3. Number and surface area of all LWD and dense LWD in 1997 and 1998 for the riprap revetment and control; and 1999 and 2000 for the bioengineered revetment and control at different river discharge rates at rkm 6.9 on the Cedar River, Washington. 12

Table 4. Number of predatory fish collected and sampled for stomach contents at the bioengineered revetment and control sites at rkm 6.9 on the Cedar River, WA, 2000. 18

Table 5. Number (N) and lengths (mm) of predator fish collected from the bioengineered revetment and control site at rkm 6.9 on the Cedar River, January to May, 2000. . 19

Table 6. Number of prey fish consumed by piscivorous fishes by date sampled at the bioengineered revetment and control site at rkm 6.9 on the Cedar River, WA, 2000. 20

Table 7. Frequency of occurrence (FO) and predation rate of piscivores consuming salmonid fry and sculpin at the bioengineered revetment and control site at rkm 6.9 of the Cedar River, WA, January to May, 2000. 21

Table A-1. Habitat survey data for 1999 34

Table A-2. Habitat survey data for 2000 36

Table B-1. Bioengineered revetment and control abundance estimates (bounded count methodology) for 1999. 38

Table B-2. Bioengineered revetment and control abundance estimates (bounded count methodology) for 2000. 39

Table B-3. Bioengineered revetment, riprap revetment, and control site abundance estimates (bounded count methodology) for single surveys in 1997, 1998, 1999, and 2000 40

INTRODUCTION

Several populations of Pacific salmonids inhabit the Cedar River, Washington. Sockeye salmon (*Oncorhynchus nerka*), chinook salmon (*O. tshawytscha*), coho salmon (*O. kisutch*), rainbow trout/steelhead (*O. mykiss*), and cutthroat trout (*O. clarki*) utilize various sections of the river during their life cycle. The lower Cedar River (below Landsburg dam) has a comprehensive system of levees and riprap revetments that protected homes and businesses.

The U.S. Army Corps of Engineers (Corps) modified the riprap revetment at the Maplewood Golf Course in 1998. The new revetment was a combination bioengineered revetment consisting of large woody debris (LWD), rock deflectors, and upslope native vegetation. LWD was incorporated for fish habitat and upslope vegetation was incorporated to provide slope stability and eventual shading. This project was undertaken for partial mitigation of the flood control project that occurred at the mouth of the Cedar River in 1998.

The U.S. Fish and Wildlife Service (FWS) found that relative to natural riverbanks, juvenile salmonid densities were greater at banks stabilized with LWD and less at sites stabilized with riprap (Peters et al. 1998). One of the FWS study locations was the riprap revetment at the Maplewood Golf Course on the Cedar River. Snorkel surveys were conducted at this location during spring and summer 1997 (June and August), and winter 1998 (February). The Corps contracted the FWS to monitor salmonid use of the bioengineered revetment during the winter (January to March) and spring (April to June) of 1999, since the FWS had background data for this location. The City of Renton requested that the FWS complete a second year of monitoring during winter and spring of 2000. It also requested that the FWS determine the level of predation on salmonids that occurred at the bioengineered revetment verses a control.

The objectives of this study were to: 1) compare habitat complexity at the bioengineered revetment to the old riprap revetment; 2) determine if the bioengineered revetment provided better habitat than the old riprap revetment by comparing relative densities of juvenile chinook salmon and other salmonids at the bioengineered revetment to the old riprap revetment; 3) compare relative densities at the bioengineered revetment to a control; and, 4) determine the level of predation on salmonids that occurs by piscivorous fish at the bioengineered revetment verses a control.

STUDY AREA

The Maplewood Golf Course bioengineered revetment is located on the Cedar River at rkm 6.9 (Figure 1). The Cedar River is one of five major rivers in King County and is the largest tributary to Lake Washington. The river drains a basin of 486.9 square kilometers that extends westward from the crest of the Cascade Mountains to the southern shore of Lake Washington at the City of Renton.

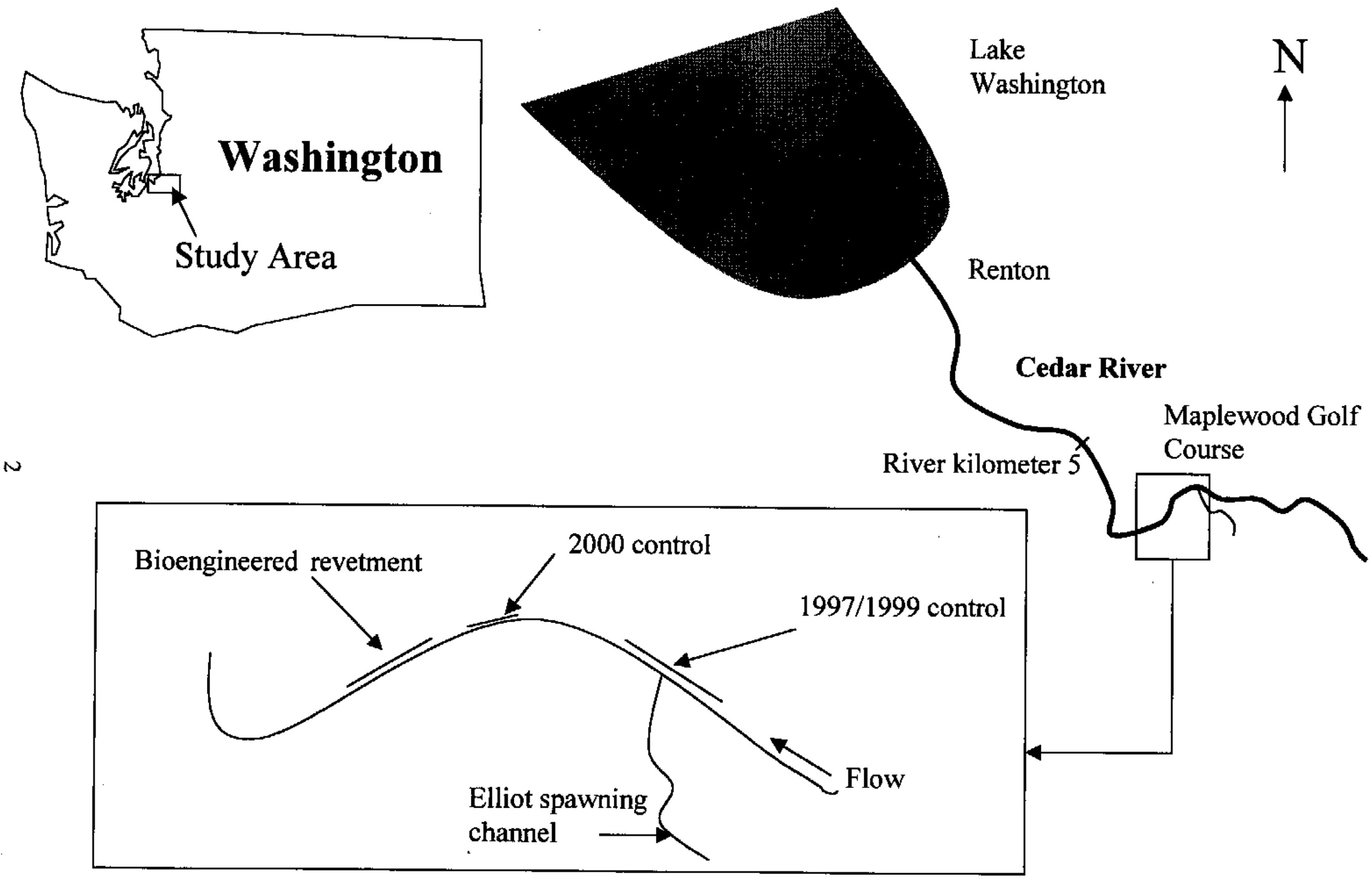

Figure 1. Location of bioengineered revetment and control sites at rkm 6.9 on the Cedar River, Washington.

The lower Cedar River watershed is heavily developed with residential and urban areas. The river has a comprehensive system of revetments and levees that, along with a dam, provides flood protection to residents in the valley, and homes and commercial property in downtown Renton (King County 1996).

The original revetment consisted of riprap. The new bioengineered revetment consists of a series of LWD structures, rock deflectors, a rock toe, and native vegetation planted along the bank (Figure 2). The bioengineered revetment study reach was 62 meters (m) long and 5 m wide. The control reach for the year 2000 surveys was approximately 25 m upstream of the bioengineered revetment. The control reach dimensions were 23 m long by 3.5 m wide and was representative of un-reveted river banks within the system. The original control reach used for all surveys until the year 2000 surveys was 60 m long and 2.5 m wide. The site was located approximately 300 m upstream of the bioengineered revetment and was directly across from the spawning channel constructed by King County.

METHODS

DATA ANALYSIS

We evaluated fish use at the bioengineered revetment using two separate comparisons. We compared relative fish densities from multiple observations collected on a bi-monthly basis at the bioengineered revetment to those at a control area. We also compared relative densities from one night survey from winter 1998 (February 11, 1998) to winter 1999 and 2000 (February 11, 1999; February 17, 2000); and from one day survey from spring 1997 (June 23, 1997) to spring 1999 and 2000 (June 28,1999; July 14, 2000). No day surveys were conducted in spring 1998 because the site was under construction. We used relative densities to account for the year to year variability in fish densities.

Control reaches selected for comparison were naturally stable areas similar in river morphology and meso-habitat features to the original riprap study reach. We used two different control units for this study. A new control reach was selected for the 2000 monitoring because the LWD at the original control had blown out during a high water event. This left the original control a homogenous habitat and unsuitable for snorkeling due to high water velocities.

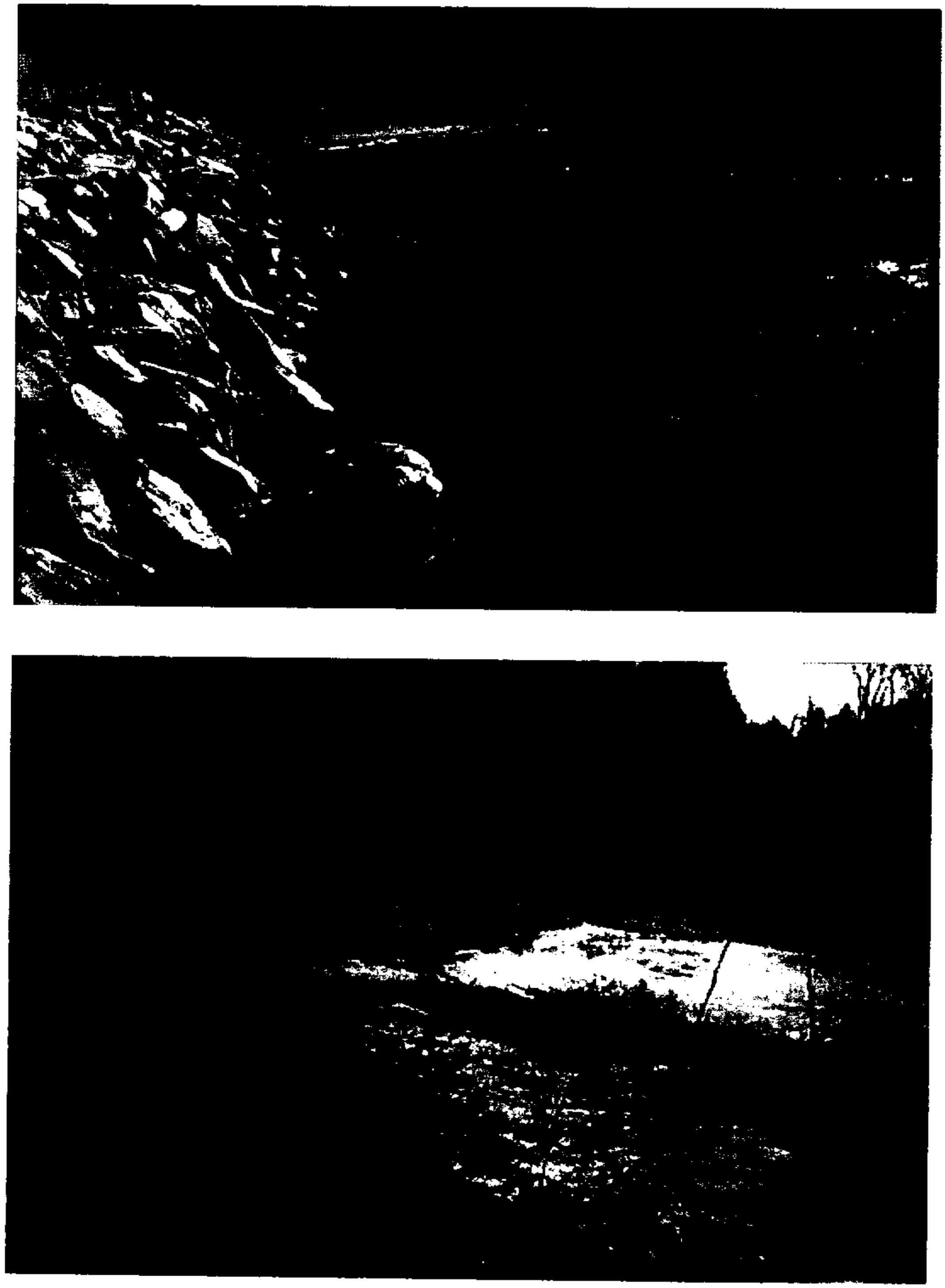

Figure 2. Top: Original Maplewood riprap revetment, summer 1997. Bottom: Bioengineered revetment with rock deflectors, LWD, and vegetated slopes, winter 1998.

HABITAT

We measured habitat at the bioengineered revetment and the control during a variety of flows. Habitat measurements were taken if flows were greater or less than 20% of the previous habitat surveys. Riverine habitats were classified as pools, riffles, glides, or runs, following Bisson et al. (1982) and Helm (1985). Pools were further classified as lateral scour, straight scour, backwater, or dead-water pools following Bisson et al. (1982). We also classified and measured secondary habitats within the project site. Secondary habitats were classified as pools, riffles, runs, or backwater/dead-water pools and had to occupy at least 20% of the wetted channel width. We measured length, width, maximum and average depth (average of three measurements per secondary habitat unit), water velocity, substrate composition and embeddedness, percent overhanging vegetation (within 30 cm of the water surface), and instream woody debris for each secondary habitat. Lengths and widths of secondary habitats were measured using a laser range finder or stadia rod. Depths were measured using a stadia rod. Water velocities within each habitat unit were measured with a Swoffer Model 2100 current meter.

Substrate composition was recorded during the snorkel surveys. We recorded the size and percent of the dominant and subdominant substrates visually based on Cummings (1962) for each secondary habitat unit (Table 1).

We compared habitat features at the bioengineered revetment and old revetment by calculating weighted variable means for secondary habitats using the following formula:

$$\overline{X} = \sum_{n}^{i=1} (L_i * X_i)/L$$

Where $\overline{X}$ is weighted mean of the measured habitat variable, L_i is the length of an individual secondary habitat, X_i is the measured habitat variable (i.e., flow, depth, etc.) for that particular habitat, and L is the total length of the site.

Woody debris was counted, classified by type, measured for length and width, and visually classified with regards to complexity. Woody debris accumulations were classified as log, tree, log jam, rootwad, or small woody debris. Woody debris had to be at least 10 cm in diameter and 3 m long to be classified as LWD. The complexity of woody debris was classified visually as sparse, medium, or dense. Single logs without branches were classified as sparse, logs with some branches as medium, and complex log jams, rootwads, or trees were classified as dense.

Table 1. Substrate classifications used for this study (Cummings 1962).

Substrate	Description/particle size range (mm)
Silt/sand	< 2
Gravel	2 - 64
Cobble	64 - 265
Boulder	>256
Bedrock	Exposed underlying rock not distinguishable as a boulder
Debris	Bottom covered with terrestrial debris such as leaf litter and/or small woody debris

FISH DENSITIES

Snorkel surveys were completed once every 2 weeks starting in January and ending in June during 1999 and 2000. Surveys were separated into winter and spring time periods. Winter surveys were conducted from the end of January to the end of March; spring surveys were conducted from the beginning of April to the end of June. Surveys were conducted at night during both periods and commenced at least one hour after sunset. Surveys were conducted at night because many fish, including salmonids, seek refuge during the day and are active at night during the winter (Heggenes et al. 1993; Riehle and Griffith 1993; Contor and Griffith 1995). We conducted one survey during the day in spring of 1999, and spring 2000, to allow comparisons to data collected in 1997. We also compared one night survey in 1998 to one night survey in 1999 and 2000.

Three snorkelers started at a downstream reference point and moved slowly upstream. The snorkelers followed one another; allowing at least 20 m between surveyors. The number of fish observed was recorded on slates attached to the snorkeler's arm. Salmonids were counted and identified to species when possible. Juvenile chinook salmon were less than 70 millimeter (mm) fork length. Salmon and trout parr (50-100 mm fork length) were grouped into one category (salmonid parr) because of the difficulty distinguishing between coho salmon, rainbow trout/steelhead, and cutthroat trout at night. Salmonids often moved away from the light which made identification difficult. Larger salmonids (including chinook salmon smolts) were grouped into 100-200 mm and 200+ mm categories. Cottids were grouped into two size groups, less than 75 mm total length (TL), and greater than 76 mm TL, but were combined into one group for relative density data analysis. All other fish were counted and identified to family or species when possible. Our data analysis was conducted only for juvenile chinook salmon, salmonid parr, total salmonids, and cottids due to a low abundance of other species during our surveys.

The total salmonid category included chinook salmon, coho salmon, sockeye salmon, age 0 trout, cutthroat trout and rainbow/steelhead trout.

Fish abundance was estimated using the bounded-count methodology (Regier and Robson 1967) as:

$$N=2N_m - N_{m-1}$$

where N is the estimate of fish abundance, N_m is the largest of the three snorkel counts, and N_{m-1} is the second largest count.

Fish densities at the control and bioengineered revetment were calculated as follows:

Bioengineered revetment density (D_r) = fish count/revetment length

Control density (D_c) = fish count/control length

We then calculated relative densities as:

Bioengineered revetment relative density = $(D_r-R_d)/R_d$

Control relative density = $(D_c-R_d)/R_d$

Where:

Reach density (R_d) = $(N_r+N_c)/(L_r+L_c)$

Where N_r and N_c are the bioengineered revetment and control fish abundance estimates, respectively, and L_r and L_c are the revetment length and control length, respectively.

The relative density value is between -1 and infinity. The negative value indicates lower than average densities, and a positive value indicates greater than average densities.

PREDATION

Predatory fish were collected and sampled for stomach contents at the bioengineered revetment and control. Sampling occurred twice in February and March, and once in April and May. Surveys began January 31, 2000, and ended May 18, 2000. Sampling occurred during the period beginning 2 hours after dusk and ending shortly after dawn. This schedule increased our ability to collect fish as most cottids and salmonids are nocturnal during winter and spring. Fish were mostly collected by backpack electrofishing, or by snorkelers using either slurp guns (hand-held suction devices) or small dip nets (mesh size 3 mm). Backpack electrofishing was used primarily to collect salmonids and snorkeling was done primarily to collect cottids. On one occasion, a beach seine was used, but was found to be less effective in comparison to other methods used.

Captured fish were identified to genus or species. Fork lengths were measured on salmonids and total lengths were measured on cottids. Stomach contents of fish greater than 49 mm were removed using a gastric flushing device modified from Foster (1977). Stomach samples obtained from individual fish were then combined with others of the same pre-defined size and species category, put in plastic bags, and placed into a cooler with ice. Samples were later froze. In the laboratory, stomach contents were thawed, placed under a dissecting scope and identified to order, family, or other major taxonomic group. Salmonids were identified to species or lowest taxonomic group possible, depending on digestive state. Other fishes were identified to genus or lowest taxonomic group possible. Separated groups were then blotted on tissue paper and weighed to the nearest 0.001 grams. Finally, sample contents were recombined and placed in plastic vials with alcohol and stored.

RESULTS

HABITAT

Habitat measurements were taken once during spring 1997 and once during winter 1998. The riprap revetment consisted of one secondary habitat unit in 1997 and two secondary habitat units in 1998. There was one secondary habitat unit at the control during both years (Table 2).

Habitat measurements were taken at four and three different discharges during 1999 and 2000, respectively. The number of secondary habitats at the bioengineered revetment varied from three to five in 1999; and from two to five in 2000. The control area had four to six secondary habitat units in 1999; and one to two in 2000 (Table 2).

There were more secondary habitats at the bioengineered revetment than the riprap revetment during most surveys (except July 14, 2001). The bioengineered revetment consisted of backwater and slow water pools, where the riprap revetment consisted of a lateral scour pool (Appendix A).

Weighted velocities at the riprap revetment were greater than 30 cm/s during the surveys in 1997 and 1998. Weighted velocities at the bioengineered revetment were less than 30 cm/s during all surveys in 1999 and 2000, and were less than 15 cm/s in six out of seven surveys during the same time period. Weighted velocities at the control sites were greater than 30 cm/s in all surveys in 1997, 1998, and 1999; but were greater than 30 cm/s in only one of three surveys in 2000 (Table 2).

Table 2. Habitat data from the riprap revetment and control site in 1997 and 1998; and the bioengineered revetment and control site in 1999 and 2000.

Site	Date	Discharge (cfs)	Length (m)	Width (m)	Number secondary habitats	Weighted velocity (cm/s)	Weighted average depth (m)	Weighted maximum depth (m)	Dominate Substrate type	Weighted dominate substrate (%)	Secondary substrate type	Weighted Secondary substrate (%)
1997												
Revetment	6-23-97	575	76	1.5	1	46.6	0.90	1.30	cobble	80	riprap	20
Control	6-23-97	575	62	2.5	1	48.2	0.70	1.40	cobble	60	hardpan	40
1998												
Revetment	2-11-98	495	76	2.5	2	42.7	0.55	1.8	gravel	70	sand	30
Control	2-11-98	495	62	2	1	39.6	1.1	2.4	gravel	40	cobble	40
1999												
Revetment	2-11-99	617	62	5	3	6.7	0.88	1.12	silt	51	gravel	36
Control	2-11-99	617	60	2.5	6	37.2	0.56	0.80	gravel	62	cobble	29
Revetment	2-22-99	1260	62	5	5	14.3	0.72	1.09	silt	63	riprap	23
Control	2-22-99	1260	60	2.5	4	46.3	2.05	2.81	cobble	32	gravel	20
Revetment	3-8-99	1050	62	5	3	29.6	0.64	1.18	silt	62	riprap	32
Control	3-8-99	1050	60	2.5	6	74.7	0.70	0.95	gravel	59	cobble	27

Table 2. Con't.

Site	Date	Discharge (cfs)	Length (m)	Width (m)	Number of secondary habitats	Weighted velocity (cm/s)	Weighted depth (m)	Weighted maximum depth (m)	Dominate substrate type	Dominate weighted substrate (%)	Secondary substrate type (%)	Weighted secondary substrate (%)
Revetment	3-22-99	677	62	5	3	5.8	0.65	0.84	silt	59	riprap	35
Control	3-22-99	677	60	2.5	6	30.8	0.75	0.99	gravel	55	cobble	27
						2000						
Revetment	2-28-00	625	62	5	5	4.3	0.35	0.67	silt	62	silt	20
Control	2-28-00	625	23	3.5	2	26.2	0.95	1.33	silt	47	gravel	30
Revetment	6-20-00	850	62	5	3	8.5	0.60	0.96	silt	53	riprap	28
Control	6-20-00	850	23	3.5	2	13.7	0.72	1.56	riprap	66	silt	33
Revetment	7-14-00	266	62	5	2	9.4	0.52	0.85	silt	65	riprap	22
Control	7-14-00	266	23	3.5	1	7.3	0.6	1.1	riprap	50	silt	40

Dominate substrate types at the bioengineered revetment changed in comparison to the riprap revetment. The dominate substrate at the riprap revetment was cobble in 1997 and gravel in 1998. The bioengineered revetment dominate substrate consisted primarily of silt during 1999 and 2000 (Table 2). Dominate substrates at the control were cobble and gravel in 1997 and 1998, respectively. Dominate substrate at the control sites were primarily gravel and cobble in 1999, and silt and riprap in 2000.

Large woody debris surface area was greater in the bioengineered revetment in 1999 and 2000 compared to the riprap revetment. The LWD surface area ranged from 42 m^2 to 72 m^2 during the 1999 and 2000 surveys, while the number of dense LWD pieces ranged from two to five during the same time period. The surface area of dense LWD decreased in 2000 compared to 1999. There was no LWD in the revetment prior to re-construction (Table 3).

FISH DENSITIES

Bi-weekly Surveys

We conducted 11 surveys in 1999 and 10 surveys in 2000 (Appendix B). Relative fish densities were generally greater for the bioengineered revetment than the control area during both 1999 and 2000 with the exception of juvenile chinook salmon. Juvenile chinook salmon relative densities changed throughout the sampling season during both years. Relative densities were generally less for the bioengineered revetment relative to the control during January through April of both years. However, juvenile chinook relative densities were generally greater for the bioengineered revetment than the control in May and June (Figures 3 and 4).

Salmonid parr (50-100 mm) relative densities were greater for the bioengineered revetment than the control during all but three surveys (June 14, 1999, April 13, 2000, May 18, 2000) (Figures 3 and 4). However, total salmonid relative densities were greater for the bioengineered revetment during the 1999 surveys. Total salmonid relative densities for the 2000 surveys were less for the bioengineered revetment during January through April 2000; but were generally greater in May and June 2000 (Figure 4). Sculpin relative densities were greater for the bioengineered revetment than the control, except for one survey during each year (February 22, 1999; April 13, 2000). We also observed coho and sockeye salmon, suckers, and stickleback in limited numbers during our surveys (Appendix B). However, numbers for these species were too low to complete any meaningful comparisons.

Table 3. Number and surface area of all LWD and dense LWD during 1997 and 1998 for the riprap revetment and control; and 1999 and 2000 for the bioengineered revetment and control at different river discharge rates at rkm 6.9 on the Cedar River, Washington.

Site	Date	Discharge (cfs)	LWD area (m^2)	Area dense LWD (m^2)	Number of dense pieces
			1997		
Revetment	6-23-97	575	0	0	0
Control	6-23-97	575	18.5	8.2	1
			1998		
Revetment	2-11-98	495	0	0	0
Control	2-11-98	495	18.9	0	0
			1999		
Revetment	2-8-99	1260	48.2	46.3	5
Control	2-8-99	1260	14.7	10.5	2
Revetment	2-22-99	617	43.0	31.8	4
Control	2-22-99	617	15.9	0	0
Revetment	3-8-99	1050	50.8	38	4
Control	3-8-99	1050	10.5	10.5	2
Revetment	3-22-99	677	72	55.8	4
Control	3-22-99	677	15.9	0	0

Table 3 con't.

Site	Date	Discharge (cfs)	LWD area (m^2)	Area dense LWD (m^2)	Number of dense pieces
			2000		
Revetment	2-28-00	625	46.0	22.0	2
Control	2-28-00	625	4.2	0	0
Revetment	6-20-00	850	41.8	26.8	4
Control	6-20-00	850	17.5	5	1
Revetment	7-14-00	266	49.0	32.6	5
Control	7-14-00	266	4.2	6.9	2

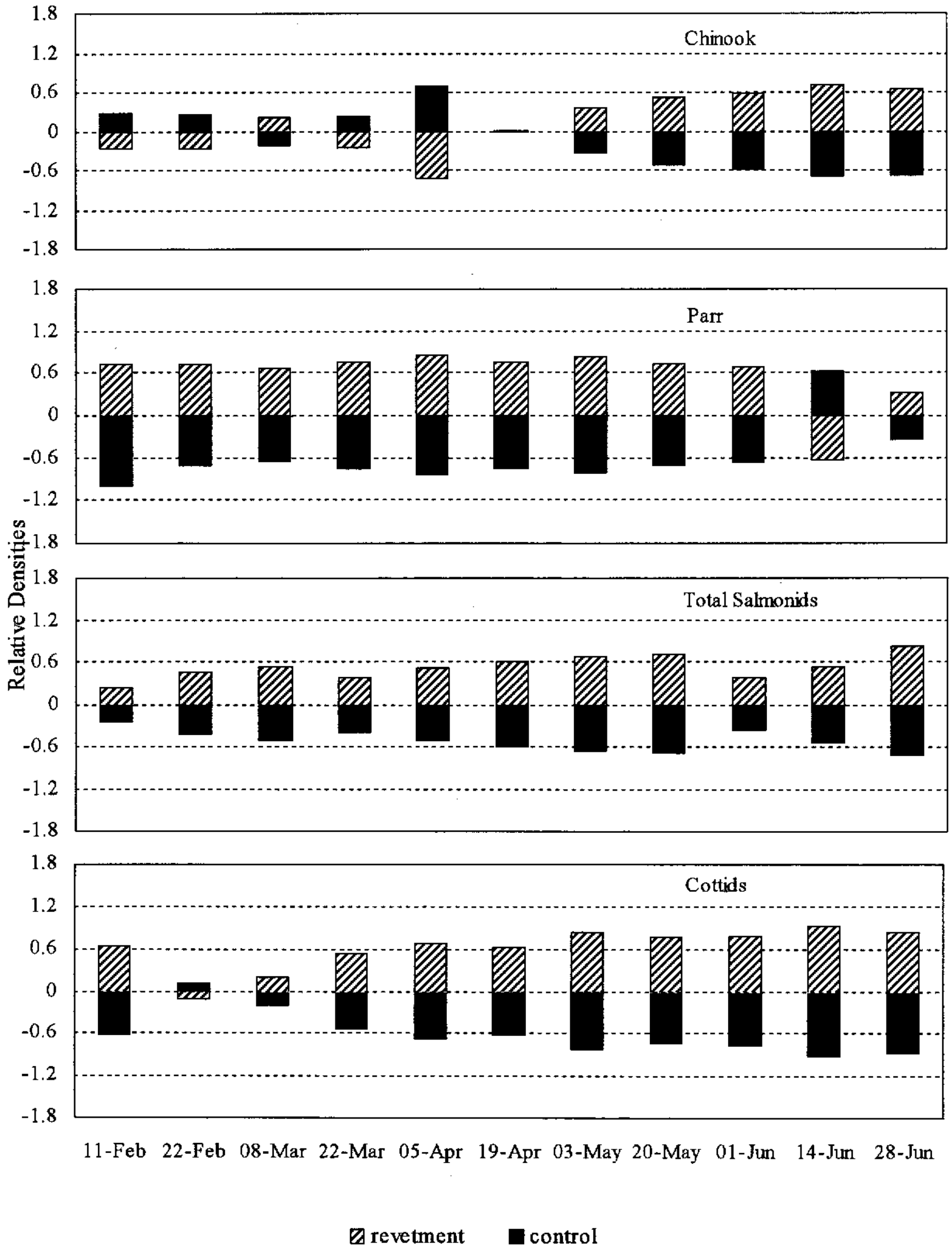

Figure 3. Relative densities of juvenile chinook salmon, salmonid parr, total salmonids, and cottids at the bioengineered revetment during 1999. The negative value indicates lower than average reach densities, and a positive value indicates greater than average reach densities.

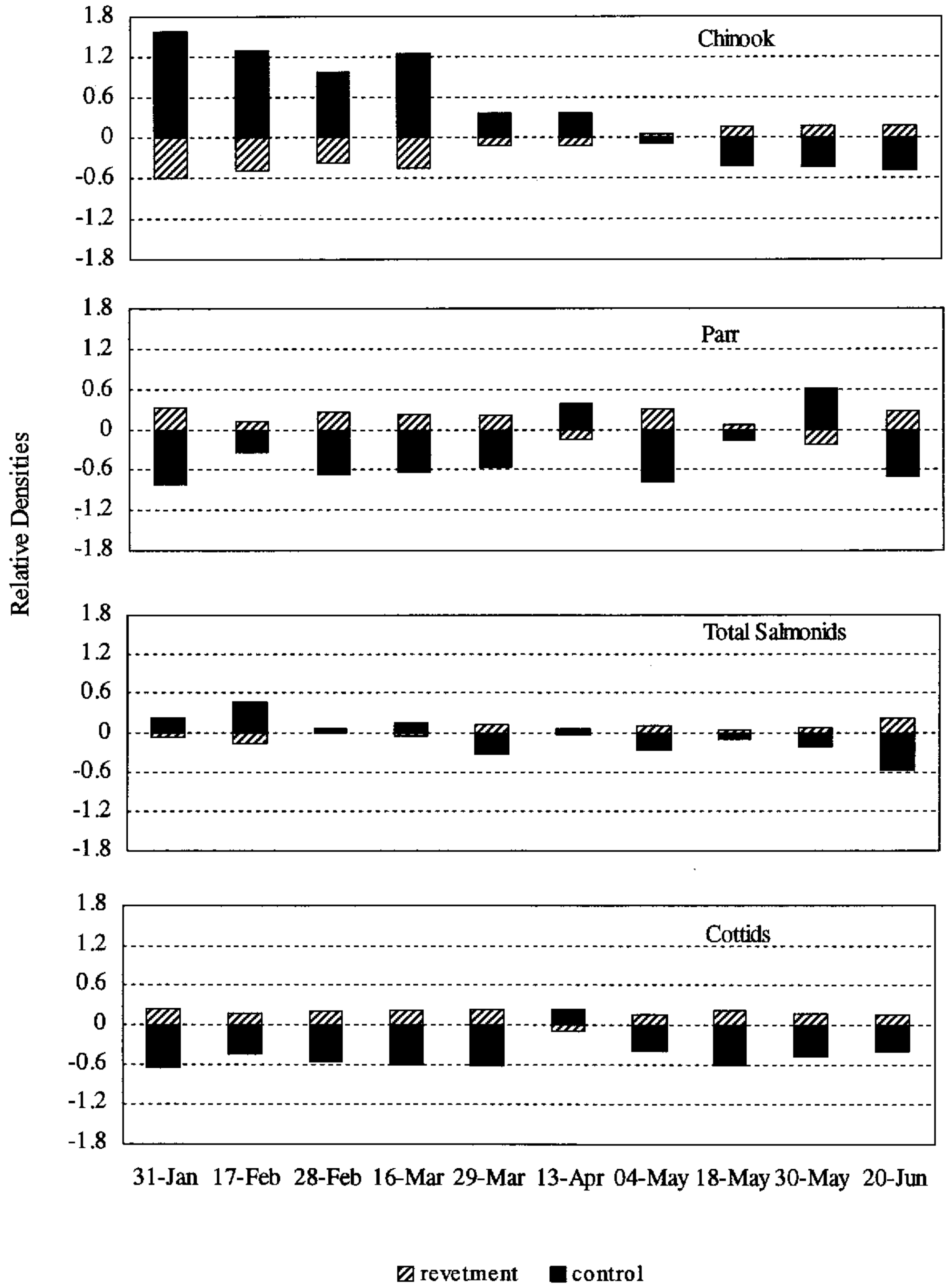

Figure 4. Relative densities of juvenile chinook salmon, salmonid parr, total salmonids, and cottids at the bioengineered revetment during 2000. The negative value indicates lower than average reach densities, and a positive value indicates greater than average reach densities.

Pre - and Post - Modification Comparisons

Relative fish densities were greater at the bioengineered revetment than the riprap revetment for all but one comparison (Figure 5). Although juvenile chinook relative densities were negative (lower than reach average) during all 3 years, they were greater in 1999 and 2000 (bioengineered revetment) than in 1998 (riprap revetment). Salmonid parr and cottid relative densities were greater in 1999 and 2000 than in 1998. Relative densities of total salmonids were greater at the bioengineered revetment in winter 1999 than the riprap revetment in winter 1998. However, relative densities of total salmonids were less at the bioengineered revetment compared to the riprap revetment in winter 1998.

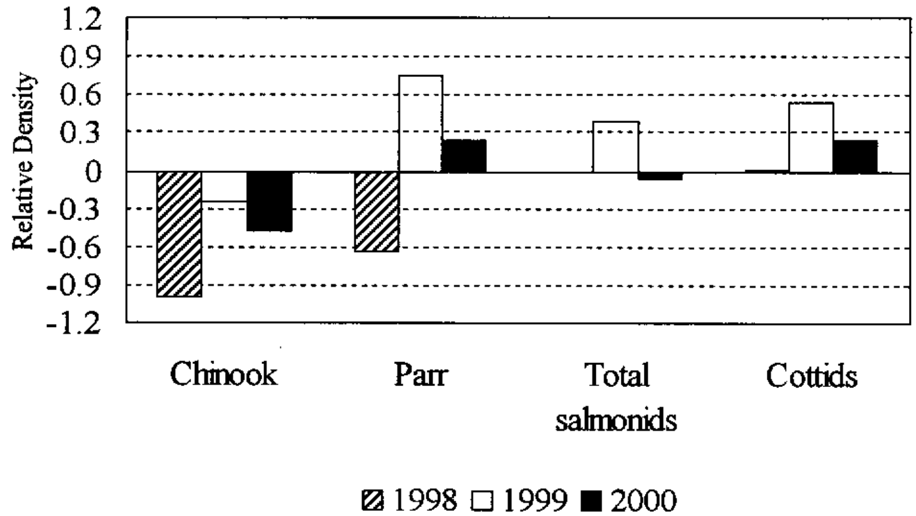

Figure 5. Comparison of juvenile chinook salmon, salmonid parr, total salmonids, and cottid relative densities during winter (night)1998 survey (old riprap revetment), and the winters of 1999 and 2000 (bioengineered revetment). The negative value indicates lower than average reach densities, and a positive value indicates greater than average reach densities. Data are from single surveys during similar times (February 11, 1998; February 11, 1999; February 17, 2000).

PREDATION

A total of 366 fish, 309 from the revetment and 57 from the control site, were sampled for stomach contents (Table 4). Twenty-one (6%) of the fish had empty stomachs. Of those having stomach contents, 291 were collected from the revetment, and 54 from the control site. Seven different predatory fish species were collected from the revetment, and five different predatory fish species from the control (Table 5). We collected 262 cottids and 47 salmonids at the revetment, and 53 cottids and 4 salmonids at the control. Cottids at the revetment had a mean length of 89.9 mm (SD = 15.1; n = 262), while cottids at the control had a mean length of 91.5 mm (SD = 11.1; n = 53). Salmonids at the revetment had a mean length of 114.7 mm (SD = 23.1; n = 47), while salmonids at the control had a mean length of 123.7 mm (SD = 11.6; n = 4) (Table 5).

Overall, predation of fish was low at both sites, and varied by species and by sampling date. Only 8% (28 of 367) of all predators sampled had fish in their stomachs. Prey fish were either salmonid fry or cottids. A majority of salmonid fry (74% (28 of 38)) were consumed by just three (0.8%) of the total number of fish sampled. Two were rainbow trout/steelhead and the other was a torrent sculpin.

A total of 50 fish were observed in the 366 predator stomach samples. The consumed fish consisted of 38 salmonid fry (1 chinook salmon, 27 sockeye salmon, and 10 unidentified fry) and 12 unidentified cottids (Table 6). Nine of the 10 unidentified salmonid fry were likely sockeye salmon and the other a chinook salmon, based on size.

The highest frequency of a predator species preying on fish was observed at the revetment, where 27% of the rainbow trout/steelhead consumed fish, all salmonid fry (Table 7). At the control, 12% of the torrent sculpin (*Cottus rhotheus*) sampled consumed fish. Of all other fish species sampled at either the revetment or control site, ≤ 8% of each predatory species had consumed fish.

Predation of salmonid fry varied by predator species at the revetment compared to the control (Table 7). Salmonid predators consumed more salmonids (0.47 fry/predator) than cottid predators (0.03 fry/predator) at the revetment. Rainbow trout/steelhead consumed the most fish per species sampled (0.95 fry/predator sampled). Other fish species consumed fry at the revetment at rates of ≤ 0.07 fry/predator sampled. Fish were only eaten by cottids at the control. Torrent sculpin consumed salmonid fry at 0.35 fry/predator. Torrent sculpin and riffle sculpin (*C. gulosus*) consumed cottids at 0.08 and 0.04 cottids/predator, respectively.

Predation of fish was fairly consistent except for one sample date (April 13, 2000). Fish were observed in stomach samples collected on all dates; however, numbers of prey fish per predator were relatively low for all dates (Table 6). The highest number of salmonid fry consumed was on April 13 (34 fry).

Table 4. Number of predatory fish collected and sampled for stomach contents at the bioengineered revetment and control sites at rkm 6.9 on the Cedar River, WA, 2000 (E = fish stomach empty at time of sample; Y = fish stomach sample obtained). Rainbow trout refers to rainbow trout/steelhead.

	Date												
	31-Jan		17-Feb		28-Feb		16-Mar		13-Apr		18-May		
Predator	E	Y	E	Y	E	Y	E	Y	E	Y	E	Y	Tot
							REVETMENT						
Cottids	**3**	**46**	**5**	**49**	**4**	**32**	**1**	**27**	**3**	**47**	**0**	**45**	**262**
Coastrange sculpin	1	4	0	0	0	0	0	0	0	0	0	1	6
Riffle sculpin	0	6	3	9	1	12	0	4	1	16	0	6	58
Shorthead sculpin	0	0	0	1	0	0	0	2	0	0	0	0	3
Torrent sculpin	2	36	2	39	3	20	1	21	2	31	0	38	195
Salmonids	**0**	**6**	**0**	**7**	**0**	**3**	**1**	**7**	**0**	**15**	**1**	**7**	**47**
Coho salmon	0	4	0	0	0	1	1	1	0	6	1	4	18
Cutthroat trout	0	1	0	0	0	0	0	2	0	3	0	1	7
Rainbow trout	0	1	0	7	0	2	0	4	0	6	0	2	22
Site total	**3**	**52**	**5**	**56**	**4**	**35**	**2**	**34**	**3**	**62**	**1**	**52**	**309**
							CONTROL						
Cottids	**0**	**11**	**0**	**3**	**0**	7	**0**	**6**	**0**	**15**	**3**	**8**	**53**
Coastrange sculpin	0	2	0	0	0	0	0	0	0	1	0	1	4
Riffle sculpin	0	2	0	1	0	4	0	2	0	9	3	2	23
Shorthead sculpin	0	0	0	0	0	0	0	0	0	0	0	0	0
Torrent sculpin	0	7	0	2	0	3	0	4	0	5	0	5	26
Salmonids	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**1**	**4**
Coho salmon	0	0	0	0	0	0	0	0	0	0	0	0	0
Cutthroat trout	0	0	0	0	0	0	0	0	0	0	0	0	0
Rainbow trout	0	0	0	1	0	0	0	0	0	2	0	1	4
Site total	**0**	**11**	**0**	**4**	**0**	7	**0**	**6**	**0**	**17**	**3**	**9**	**57**
Grand total	**3**	**63**	**5**	**60**	**4**	**42**	**2**	**40**	**3**	**79**	**4**	**61**	**366**

Table 5. Number (N) and lengths (mm) of predator fish collected from the bioengineered revetment and control site at rkm 6.9 on the Cedar River, January to May, 2000. Cottids were measured by total length (TL) and salmonids by fork length (FL). Totals are bolded. N = sample size and SD = standard deviation. Rainbow trout refers to rainbow trout/steelhead.

	Revetment					Control				
		Length (mm)					Length (mm)			
Predatory species	N	min	max	mean	SD	N	min	max	mean	SD
Cottids	**262**	**52**	**150**	**89.9**	**15.1**	**53**	**60**	**112**	**91.5**	**11.1**
Coastrange sculpin	6	65	99	83.5	12.9	4	90	105	96.0	6.4
Riffle sculpin	58	52	124	92.9	17.1	23	71	112	88.0	10.6
Shorthead sculpin	3	101	120	109.7	9.6	0	—	—	—	—
Torrent sculpin	195	52	150	89.0	14.3	26	60	112	93.9	11.3
Salmonids	**47**	**85**	**200**	**114.7**	**23.1**	**4***	**113**	**137**	**123.7**	**11.6**
Coho salmon	18	90	124	103.3	8.2	0	—	—	—	—
Cutthroat trout	7	93	137	108.3	14.7	0	—	—	—	—
Rainbow trout	22	85	200	126.2	28.2	4	113	137	123.7	11.6

*Excludes one unknown trout (FL 82 mm) sampled for stomach contents.

Table 6. Number of prey fish consumed by piscivorous fishes by date sampled at the bioengineered revetment and control site at rkm 6.9 on the Cedar River, WA, 2000 (unk. = unknown). Rainbow trout refers to rainbow trout/steelhead.

		Date						
Prey	Predator	31-Jan	17-Feb	28-Feb	16-Mar	13-Apr	18-May	Total
		REVETMENT						
Chinook fry	Rainbow trout	0	1	0	0	0	0	1
Sockeye fry	Riffle sculpin	0	0	1	0	1	0	2
	Torrent sculpin	0	0	1	1	1	0	3
	Coho salmon	0	0	0	0	1	0	1
	Rainbow trout	0	0	0	0	13	0	13
Unk. salmonid fry	Riffle sculpin	0	0	0	0	2	0	2
	Torrent sculpin	0	1	0	0	0	0	1
	Rainbow trout	0	0	0	0	7	0	7
Cottids	Torrent sculpin	1	1	0	3	1	2	8
	Total	**1**	**3**	**2**	**4**	**26**	**2**	**38**
		CONTROL						
Sockeye fry	Torrent sculpin	0	0	0	0	8	0	8
Cottids	Riffle sculpin	0	0	1	0	0	1	2
	Torrent sculpin	0	0	0	0	0	2	2
	Total	**0**	**0**	**1**	**0**	**8**	**3**	**12**
	Grand total	**1**	**3**	**3**	**4**	**34**	**5**	**50**

Table 7. Frequency of occurrence (FO) and predation rate of piscivores consuming salmonid fry and sculpin at the bioengineered revetment and control site at rkm 6.9 of the Cedar River, WA, January to May, 2000. FO% = percent of predators sampled consuming prey item. Predation rate = (# of prey fish) / (# of predators sampled).

	Revetment				Control			
Piscivore	Num. of predators sampled	Num. of prey fish consumed	FO (%)	Predation rate	Num. of predators sampled	Num. of prey fish consumed	FO (%)	Predation rate
Prey item: Salmonid fry								
Cottids	259	8	3	0.03	53	9	6	0.17
Coastrange sculpin	6	0	0	0.00	4	0	0	0.00
Riffle sculpin	58	4	7	0.07	23	0	0	0.00
Torrent sculpin	195	4	2	0.02	26	9	12	0.35
Salmonids	47	22	15	0.47	5	0	0	0.00
Cutthroat trout	7	0	0	0.00	0	0	0	0.00
Rainbow trout/steelhead	22	21	27	0.95	4	0	0	0.00
Unknown trout	—	—	—	—	1	0	0	0.00
Coho salmon	18	1	6	0.06	0	0	0	0.00
Prey item: Cottids								
Cottids	259	8	3	0.03	53	3	6	0.06
Coastrange sculpin	6	0	0	0.00	4	0	0	0.00
Riffle sculpin	58	0	0	0.00	23	1	4	0.04
Torrent sculpin	195	8	4	0.04	26	2	8	0.08
Salmonids	47	0	0	0.00	5	0	0	0.00

Major dietary items of predatory fishes included aquatic insects, other invertebrates (e.g., adult Diptera, terrestrial insects, earth worms, and exuvia), fish, and fish eggs (Figure 6). Aquatic insects were the most important food item by weight for all species sampled at the revetment, except for cutthroat trout, which consumed mostly other types of invertebrates. Aquatic insects or other invertebrates were also the most important food items by weight for all species sampled at the control site except for torrent sculpin. Fish was the most important food item by weight in the diet of torrent sculpin sampled; however, only 19% (5 of 26) of them had fish in their stomachs.

Predation diets varied seasonally, however, no pattern of preference by species was apparent in the three most frequently collected predators (torrent sculpin, riffle sculpin, and rainbow trout/steelhead; Figure 7-8). Aquatic insects and other invertebrates were the most abundant food items by weight for most dates sampled. Fish were observed in stomachs sampled during February, March, and April. Fish eggs were present in samples obtained on May 18.

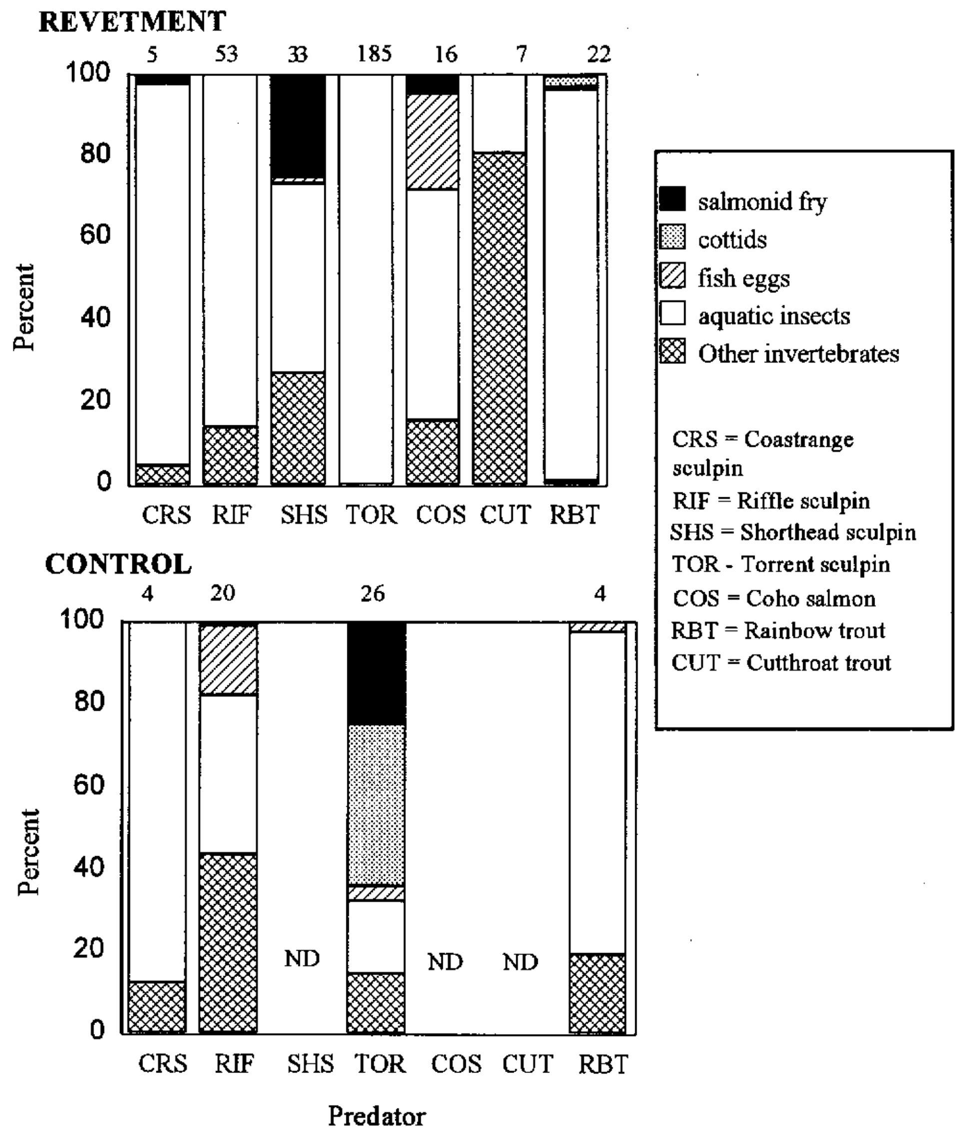

Figure 6. Composition (percent by weight) of ingested food for four species of cottids and three species of salmonids, all >49 mm TL, collected from the bioengineered revetment and control site at rkm 6.9 of the Cedar River, WA, 2000. Number of fish stomachs that contained prey items is given above each graph. ND = no data.

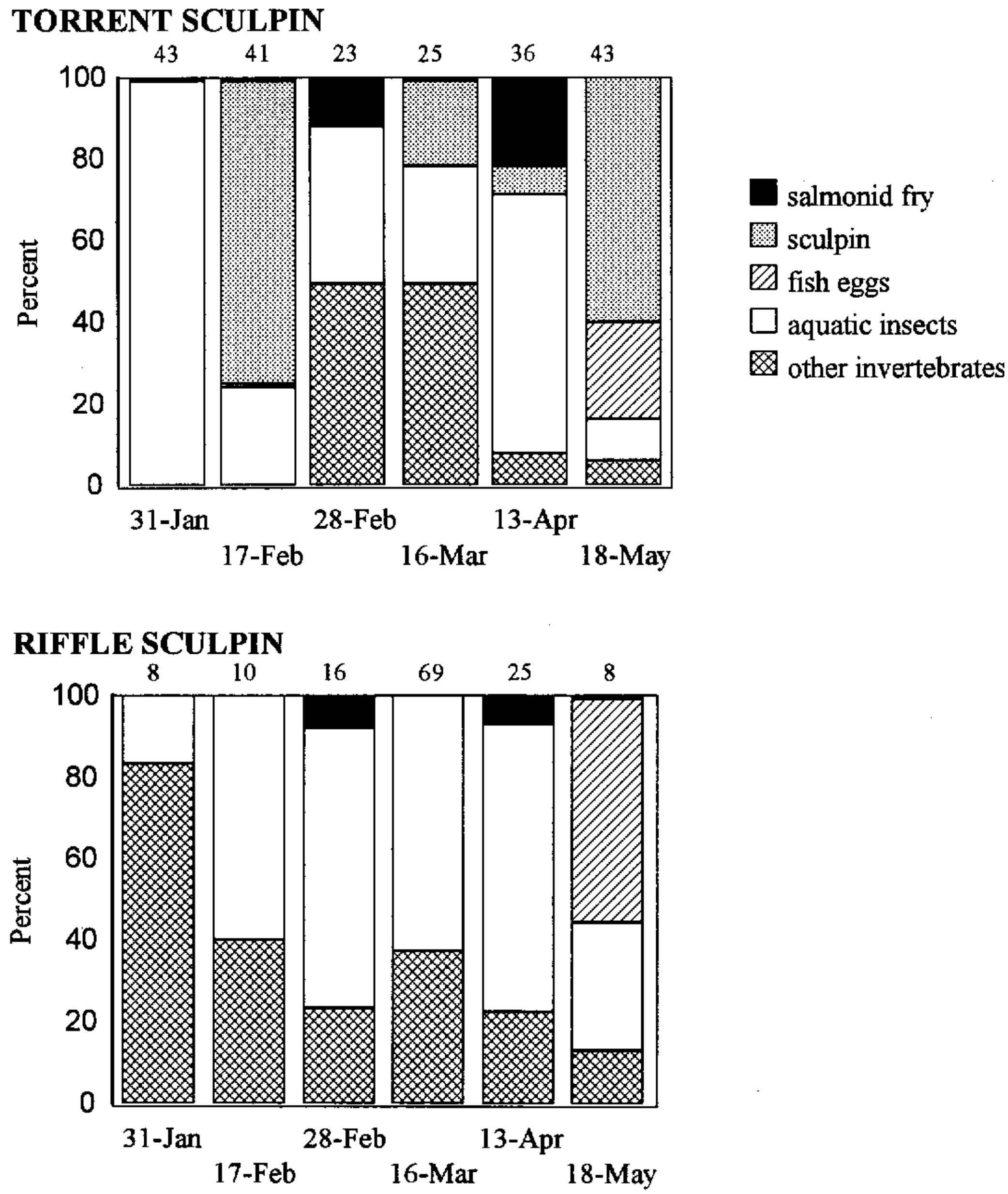

Figure 7. Composition (percent by weight) of ingested food by date for two species of cottids (>49 mm FL) collected from the bioengineered revetment and control site at rkm 6.9 of the Cedar River, WA, 2000. Number of fish stomachs that contained prey items is given above each graph. ND = no data.

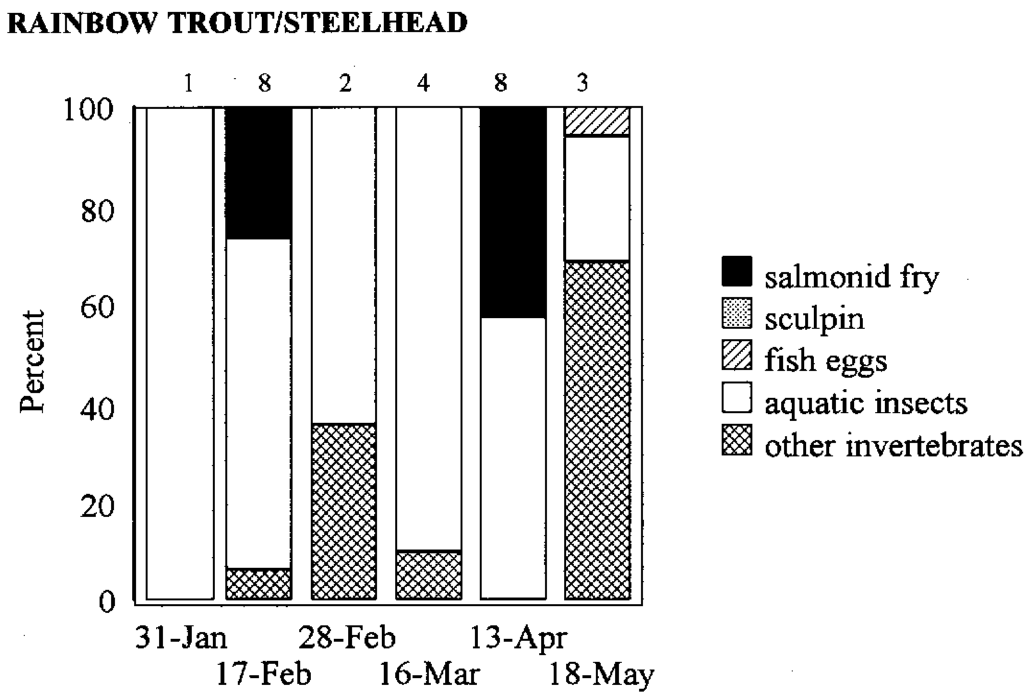

Figure 8. Composition (percent by weight) of ingested food by date for rainbow trout >49 mm FL collected from the bioengineered revetment and control site at rkm 6.9 of the Cedar River, WA, 2000. Number of fish stomachs that contained prey items is given above each graph.

DISCUSSION

The bioengineered revetment at the Maplewood Golf Course appears to be an improvement over the old riprap revetment in terms of habitat complexity and suitability for salmonids. The bioengineered revetment contained more secondary habitats than the riprap revetment, had more favorable water velocities, and complex LWD which was lacking at the riprap revetment. Relative densities of salmonids at the bioengineered revetment were also generally greater than those observed at the control with the exception of juvenile chinook salmon which changed seasonally. Relative fish densities were greater at the bioengineered revetment than the riprap revetment in seven of eight comparisons.

The bioengineered revetment is the type defined as a combination project consisting of LWD, rock deflectors, and upslope plantings (Peters et al. 1998). Peters et al. (1998) found that combination projects had more secondary habitats than the control areas they examined. In contrast, we observed more secondary habitat units at the control than the bioengineered revetment in three out of four surveys in 1999. However, the bioengineered revetment had more secondary habitats during all surveys in 2000. The change in secondary habitats in the control relative to the bioengineered revetment is probably due to the fact that we had to find a new control unit for the 2000 surveys since the old control unit changed drastically from 1999 to 2000. This change resulted from the loss of LWD during a high water event. This left the control area unrepresentative of the original riprap revetment.

The primary benefit of the increased number of secondary habitats was to provide more suitable water velocities for juvenile fish. Juvenile salmonids generally prefer velocities less than 30 cm/s (Murphy and Koski, 1989; Beecher et al. 1993). Average weighted velocity at the bioengineered revetment was less than 30 cm/s, while it was greater than 45 cm/s at the riprap revetment. Hillman et al. (1989) noted that the lack of nighttime resting areas could lead to unnecessary energy consumption by juvenile salmonids. This may result in decreased fitness because the fish must expend energy to maintain position within the water column. Thus, strictly from a velocity perspective, habitat at the bioengineered revetment was more suitable than that present at the riprap revetment.

The bioengineered revetment had much more LWD than the riprap revetment in which LWD was lacking. We believe the incorporation of well placed, complex LWD probably provided a benefit to this project. Several investigators have found salmonid abundance to be closely related to LWD, especially during winter months (Bustard and Narver 1975; Tschaplinski and Hartman 1983; Murphy et al. 1986; Hartman and Brown 1987). Size and complexity of LWD has also been related to juvenile salmon densities (Peters et al. 1996, 1998). More than half the LWD surface area at the bioengineered revetment was complex. Forward (1984) noted that LWD increases microhabitat complexity which increases the likelihood for multiple species to co-exist in close proximity with each other. We also found there was a multitude of species co-existing in the bioengineered revetment (Appendix B).

Overall, rearing fish appeared to benefit from the increased habitat complexity described above. This contrast results described by Peters et al. (1998). They observed lower fish densities at combination projects than at natural control areas. However, the authors attributed this to the poor placement and lack of complexity of LWD at the projects they examined. In contrast, LWD at the bioengineered revetment was well placed, complex, and created debris jams that were of significant size.

Juvenile chinook salmon were observed in habitats near the river bank that had shallow water, low water velocity, and gradual slopes (less than 20^0, authors' personal observations). Lister and Genoe (1970) and Peters et al. (in prep) also found juvenile chinook salmon associated with marginal areas, close to cover, and adjacent to high velocities (> 40 cm/s). The bioengineered and riprap revetment lacked gradual sloping habitat. However, these habitat types were present in both control sites. The toe rock at the bioengineered and riprap revetment created a nearly vertical wall from the toe to the water surface at most discharges.

Juvenile chinook salmon relative densities were lower than average at the bioengineered revetment compared to the control during January through April; but were greater from May through June. This change may be related to temporal changes in habitat selection and/or predator avoidance. Hillman et al. (1989) found nighttime habitat selection by juvenile chinook salmon changed with time. During spring and summer, habitat selection appeared to be influenced by growth. Juvenile chinook salmon tended to move into faster and deeper water as they increased in size. Juvenile chinook salmon may have selected the bioengineered revetment as a holding or feeding point during spring migration downstream towards Lake Washington. However, it is possible that a portion of the juvenile chinook salmon we observed selected the bioengineered revetment for rearing.

Relative densities of predatory fish were greater at the bioengineered revetment than the control throughout the survey and were generally very high. This may have resulted in avoidance of the bioengineered revetment by juvenile chinook salmon until later in the year when they reached a size where predation risk was significantly reduced. Hillman et al. (1989) believed that habitat selection was a result of predator avoidance. Stein (1979) indicates that predators can influence habitat selection and distribution of prey within a stream. He also indicated that the presence of certain predators can shape prey behavioral patterns. Our results indicate that juvenile chinook salmon habitat selection changed seasonally. Whether this is due to predator avoidance is unsubstantiated since we only found one chinook salmon fry eaten by a predator.

Predation rates of salmonid fry at the bioengineered revetment and the control site were relatively low in comparison to other reported rates in the Cedar River (Tabor et al. 1998; R. Tabor, unpublished data). This may have been due to streamflow, fry abundance, and habitat type. Streamflow is an important variable affecting predation rates of sockeye salmon fry (Seiler and Kishimoto 1997; Tabor et al. 1998). Streamflow during this study was consistently at moderate levels (Seiler and Kishimoto 1997) during days predator diets were sampled, ranging from 530 to

644 cfs. Predation rates may be substantially higher under low streamflow conditions (375-450 cfs). Sockeye salmon fry emigrating to the lake typically migrate close to the surface in the thalwag, inhabiting the areas with the highest water velocities. As streamflows are reduced, water velocities are reduced, channel roughness is increased, migration time is increased and the likelihood of encountering predatory fish increases.

Prey abundance also influences predation rates (Tabor et al. 1998). Adult sockeye salmon escapement in 1999 was the lowest on record. Therefore, the number of sockeye salmon fry migrating through the revetment site and the control site was probably low throughout the sample period in 2000 and likely contributed to the low predation rates observed. Peak outmigration of wild sockeye salmon fry from the Cedar River generally occurs in early April. The highest observed predation occurred on the April 13 sample. We sampled on one night (February 18) after a release of 247,000 hatchery sockeye salmon fry at rkm 22. Given the large number of fry, we were surprised at the low level of predation that night. However, a combination of moderate streamflow (630 cfs) and low water temperature (6.3°C) may have kept predation rates at a low level.

Recent work on sockeye salmon fry in the Cedar River indicated that most predation occurs in large deep pools, especially if large woody debris or back eddies are present (R. Tabor, unpublished data). These pools are categorized as primary pools because they occupy more than 50% of the wetted channel width (Schuett-Hames et al. 1994). As fry move downstream, most or all of them must swim through the pools where large trout and sculpin are present. The bioengineered revetment site and the control site would be best described as secondary pools because they occupy less than 50% of the wetted width (R. Tabor, unpublished data). This may allow room for many of the fry to avoid the bioengineered revetment and not encounter predatory fishes. However, the bioengineered revetment and control sites do have back eddies and LWD where some predation would be expected.

CONCLUSIONS AND RECOMMENDATIONS

The bioengineered revetment consisting of LWD, rock deflectors, and planting along the bank appeared to be an improvement over the riprap revetment. The backwater and slow-water refuge the LWD and rock deflectors created increased habitat complexity for juvenile salmonids. This generally resulted in greater fish use relative to an unmodified control area in the Cedar River; and relative to fish use at the old riprap revetment. However, it only appeared to benefit juvenile chinook salmon seasonally (May through June). The habitats created by the bioengineered revetment also increased habitat area for potential predators of juvenile salmonids, especially sculpin. Although there were relatively large numbers of sculpin in the bioengineered revetment there was very little predation. Moderate streamflow, low abundance of prey, and habitat types may have contributed to the low predation rates.

Future projects could be improved by eliminating the rock toe between the rock deflectors when possible or providing a gentler slope at the water's edge, and increasing the planting near the water's edge. Peters et al. (in prep.) observed more chinook in areas with gradual slopes than steep slopes. Eliminating or modifying the rock toe to provide a more gradual slope likely would have benefitted juvenile chinook. This also would have reduced habitat for predatory sculpin, which are found in greater densities along riprapped banks than natural banks (Peters et al. 1998). However, the potential impacts of the removal of the rock toe was not addressed as part of our study. Removal of the rock toe may increase the susceptibility of the site to severe erosion. In addition, it should be noted that removal of the rock toe may not be a feasible project upon further investigation.

Increased planting near the waters edge would increase overhanging vegetation near the water surface (< 30 cm). Peters et al. (1998) found that fish densities along stabilized banks and their controls were significantly related to overhanging vegetation (within 30 cm of water surface). The bioengineered revetment lacked any overhanging vegetation.

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APPENDIX A. Habitat data used for habitat comparison 1999 and 2000.

Table A-1. Habitat survey data for 1999

Date	Site	Discharge	Number of secondary habitats	Project length (m)	Habitat type	Ave. length (m)	Ave. width (m)	Ave. flow (ft/s)	Ave. depth (m)	Max. depth (m)	Primary substrate type	Primary substrate (%)	Secondary substrate type	Secondary substrate (%)
2-8-99	Revetment	1260	5	62	backwater	14	6	0.02	0.60	0.80	silt	75	riprap	25
					run	5	3.5	0.03	0.70	0.80	gravel	90	silt	10
					backwater	8	4.5	0.02	0.50	0.70	silt	80	riprap	10
					lateral	20	4.5	0.97	0.70	1.00	silt	60	gravel	20
					backwater	15	4	0.59	1.00	1.80	riprap	40	gravel	40
2-8-99	Control	1260	4	62	backwater	12	2	1.91	2.60	3.20	cobble	50	gravel	50
					run	10	2	1.67	2.50	3.00	gravel	60	cobble	30
					backwater	12	2	0.65	3.00	3.50	clay	70	cobble	30
					lateral	37	2	1.31	1.00	1.80	n/d	n/d	n/d	n/d
2-22-99	Revetment	617	3	62	backwater	15	3	0.02	1.20	1.90	riprap	40	gravel	40
					run	34	3	0.40	0.90	1.00	silt	50	gravel	40
					dead	12	3	0.00	0.50	0.60	silt	75	riprap	25
2-22-99	Control	617	6	62	backwater	12	2	0.00	0.00	0.00	gravel	60	cobble	40
					run	21	2	2.23	0.60	0.70	gravel	60	cobble	30
					backwater	5	2	0.17	0.60	1.00	boulder	50	cobble	30
					lateral	15	2	1.70	0.80	1.20	clay	70	cobble	10
					backwater	4.5	2	0.01	0.40	0.80	silt	60	gravel	40
					lateral	6	2	0.63	1.00	1.50	cobble	60	gravel	40
3-8-99	Revetment	1050	3	62	dead	13	3.5	0.00	0.50	0.80	silt	60	riprap	40
					run	32	4.	1.48	0.50	0.80	silt	60	riprap	30
					backwater	17	3	0.74	1.00	2.20	silt	70	riprap	30

n/d = no data

Table A-1. Con't

Date	Site	Discharge	Number of secondary habitats	Project length (m)	Habitat type	Ave. length (m)	Ave. width (m)	Ave. flow (f/s)	Ave. depth (m)	Max. depth (m)	Primary substrate type	Primary substrate (%)	Secondary substrate type	Secondary substrate (%)
3-8-99	Control	1050	6	62	eddy	13	1.50	1.44	0.50	0.90	gravel	60	cobble	40
					run	16.5	2.00	2.27	0.80	0.90	gravel	60	cobble	30
					eddy	4	1.20	0.42	0.60	1.00	boulder	50	cobble	30
					run	16.5	1.50	5.23	1.00	1.20	clay	70	cobble	10
					eddy	7.5	3.00	0.17	0.40	0.70	silt	60	gravel	40
					lateral	3	2.00	2.95	0.90	1.40	cobble	60	gravel	40
3-22-99	Revetment	677	3	62	dead	13	4.00	0.00	0.50	0.70	silt	70	riprap	30
					glide	31	4.00	0.15	0.70	0.80	silt	60	gravel	40
					backwater	15	3.00	0.46	0.80	1.20	silt	60	riprap	40
3-22-99	Control	677	6	62	backwater	12	2.00	1.08	0.80	1.10	gravel	60	cobble	40
					lateral	19	2.00	1.24	0.70	0.85	gravel	60	cobble	30
					backwater	4.5	1.80	0.18	0.75	1.20	boulder	50	cobble	30
					lateral	12	2.00	2.02	1.00	1.30	clay	70	cobble	10
					backwater	8	2.50	0.06	0.80	1.10	silt	60	gravel	40
					lateral	2	1.50	0.72	1.20	1.60	cobble	60	gravel	40

Table A-2: Habitat survey data for 2000.

Date	Site	Discharge	Number of secondary habitats	Project length (m)	Habitat type	Ave. length (m)	Ave. width (m)	Ave. flow (f/s)	Ave. depth (m)	Max. depth (m)	Primary substrate type	Primary substrate (%)	Secondary substrate type	Secondary substrate (%)
2-28-00	Revetment	625	5	62	glide	15	7	0.26	0.55	0.7	silt	60	silt	30
					dead water	5	5.5	0	0.3	0.6	silt	100		0
					glide	20	4.5	0.22	0.05	0.7	silt	80	riprap	20
					eddy	7.5	4.5	0.13	0.8	1.2	silt	80	riprap	20
					dead water	6	4.5	0	0.8	1.1	riprap	50	gravel	50
2-28-00	Control	625	2	18.5	eddy	4.5	3	0.34	0.8	1.1	silt	70	gravel	30
					lateral pool	14	2	1.03	1	1.4	gravel	40	silt	30
6-20-00	Revetment	850	3	62	glide	31	7	0.29	0.4	0.7	silt	60	riprap	20
					lateral pool	17	4	0.19	0.6	1	gravel	30	riprap	30
					eddy	16	5	0.32	0.9	1.3	gravel	60	riprap	40
6-20-00	Control	850	2	18.5	lateral pool	12.5	4	0.5	0.4	1.5	riprap	70	silt	30
					eddy	6	2.5	0.35	1.4	1.7	silt	60	gravel	40
7-14-00	Revetment	266	2	62	glide	43	3	0.4	0.35	0.6	silt	70	riprap	20
					eddy	17	4	0.13	1	1.6	silt	60	riprap	30
7-14-00	Control	266	1	18.5	lateral pool	18	4	0.24	0.6	1.1	riprap	50	silt	40

APPENDIX B. Fish abundance estimated at the bioengineered revetment and control during 1997, 1998, 1999, and 2000 .

Table B-1. Bioengineered revetment and control abundance estimated (bounded count methodology) for 1999.

Date	Site	Chinook	Coho	0 age trout	Parr 50-100	Trout 100-200	Trout 200+	Sockeye	Sculpin	Sucker	Stickleback
2-11-99	Revetment	7	0	0	49	0	0	0	10	0	0
	Control	12	0	0	8	0	2	0	13	0	2
2-22-99	Revetment	8	0	0	23	0	0	0	21	0	0
	Control	15	0	0	0	2	0	2	5	0	0
3-8-99	Revetment	30	0	2	47	9	2	4	13	0	0
	Control	20	0	0	10	0	0	0	9	0	0
3-22-99	Revetment	16	0	0	54	7	0	9	58	0	0
	Control	26	0	0	8	0	0	5	18	0	0
4-5-99	Revetment	3	0	0	72	8	2	5	100	0	0
	Control	18	0	2	6	1	0	2	20	0	0
4-19-99	Revetment	12	0	0	81	10	1	7	78	0	0
	Control	12	0	2	12	0	2	0	19	0	0
5-3-99	Revetment	16	0	6	111	4	0	2	102	0	0
	Control	8	0	0	11	4	1	4	10	0	0
5-20-99	Revetment	15	14	0	49	27	8	2	131	0	0
	Control	5	0	4	8	2	1	1	19	0	0
6-1-99	Revetment	55	0	0	26	16	2	3	202	0	0
	Control	15	0	8	5	5	0	14	27	0	0
6-14-99	Revetment	110	3	0	4	47	6	0	370	0	0
	Control	20	3	1	18	10	0	0	18	0	0
6-28-99	Revetment	39	0	14	6	50	6	13	307	5	0
	Control	8	0	1	3	6	2	0	24	0	0

Table B-2. Bioengineered revetment and control abundance estimated (bounded count methodology) for 2000.

Date	Site	Chinook	Coho	0-age trout	Parr 50-100	Trout 100-200	Trout 200+	Sockeye fry	Sculpin	Suckers	Stickleback
1-31-00	Revetment	6	0	0	19	11	1	0	130	0	5
	Control	15	0	0	1	3	0	0	14	0	11
2-17-00	Revetment	17	0	0	27	16	3	0	45	0	2
	Control	30	0	0	6	4	3	0	8	0	0
2-28-00	Revetment	42	0	0	42	47	5	0	104	0	7
	Control	51	0	0	4	0	0	1	25	0	2
3-16-00	Revetment	14	0	0	35	8	0	11	65	0	0
	Control	23	0	0	4	5	0	0	8	0	2
3-29-00	Revetment	30	0	0	60	49	4	0	102	0	0
	Control	18	0	0	8	7	0	0	16	0	0
4-13-00	Revetment	60	0	0	19	38	17	0	125	0	0
	Control	36	0	0	12	2	6	0	67	0	0
5-4-00	Revetment	48	17	0	68	32	2	0	175	0	0
	Control	16	4	0	4	13	6	0	36	0	0
5-18-00	Revetment	84	0	0	37	19	11	0	234	0	0
	Control	16	0	0	11	20	3	0	32	0	0
5-30-00	Revetment	77	6	0	11	12	4	0	366	0	0
	Control	14	10	0	9	4	2	0	40	0	0
6-20-00	Revetment	24	8	8	22	18	11	0	552	5	0
	Control	4	0	0	2	5	10	0	40	0	0

B-3. Bioengineered revetment, riprap revetment, and control site abundance estimated (bounded count methodology) for single surveys in 1997, 1998, 1999, and 2000.

Date	Period	Site	Chinook	Coho	0 age trout	Parr 50-100	Trout 100-200	Trout 200+	Sockeye	Sculpin	Sucker	Stickleback
6-23-97	Spring	Revetment	0	0	0	0	0	0	0	0	10	0
		Control	0	3	0	0	0	0	0	0	0	0
2-11-98	Winter	Revetment	0	0	0	0	0	0	0	4	0	0
		Control	0	0	0	0	0	0	0	2	0	0
6-28-99	Spring	Revetment	0	0	11	0	0	5	2	0	0	0
		Control	1	0	4	3	5	3	2	4	0	0
7-14-00	Spring	Revetment	11	0	0	10	2	0	0	7	0	0
		Control	0	0	6	12	3	2	0	2	0	0

* These estimates do not include 2 unknown salmonid fry in 1998. Spring surveys were during the day, winter survey was conducted at night.